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# CalSol Portfolio

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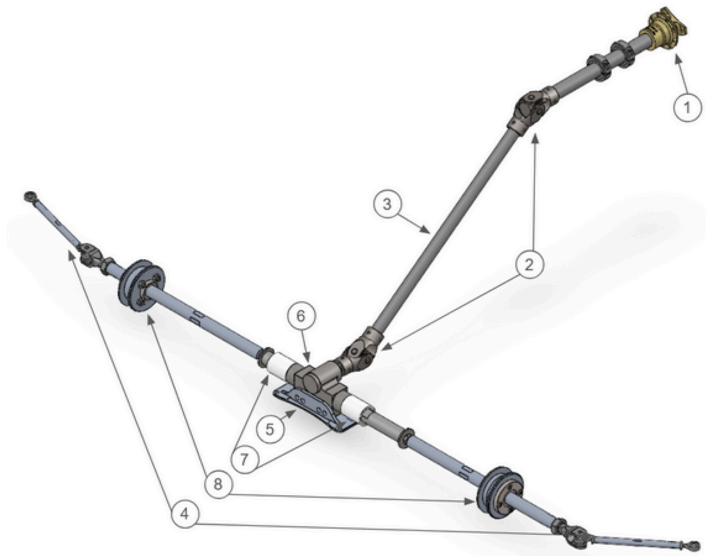
# 1. Gen 11 Steering System

**Detailed Critical Design Review Slidedeck**




### Objective

Designed, engineered, and validated the complete steering architecture for CalSol's 11th‑generation solar vehicle, optimizing for safety, rigidity, steering precision, manufacturability, and seamless integration with suspension geometry. The system balances turning performance, structural robustness, anti-bump behavior, and lightweight design to meet our goal/regulation constraints.

### Methodology

Developed the steering system using a requirements-driven engineering workflow:

Vehicle Kinematics & Requirements Definition:
Ensured compliance with Ackermann steering geometry while achieving a 7.5 m turning radius (ASC regulation), limiting wheel steering angles to under 25°, maintaining steering wheel < 500° lock to lock, and preserving anti-bump dictated by front suspension a-arm + tie rod geometry.

PowerSketch Geometry Derivation:
Used SolidWorks sketching to define linkage relationships, solve rack travel, steering axis alignment, tie-rod positioning, and steering knuckle offsets. Final tie-rod length constrained to 6.83 in, defining steering knuckle X-offset of 3.18 in, with optimized Y-offset of 3.8 in to avoid upright interference and reduce rack travel.

Structural Design & FEA Validation:
Simulated for worst-case curb impact steering load based on driver torque → resulting ~7878 N tie-rod load, then performed full-system component analysis:

- Tie rod (6061-T6): axial FOS 2.75, buckling FOS 1.41
- Custom clevis rod end (1144 steel): FOS 1.14 (realistic operating FOS ~10.4)
- Rack extensions (7075-T6): buckling FOS 4.0, <0.2 mm displacement

- Linear rail inserts designed to remove large moment arms + protect chassis paneling
- Rack & pinion mount validated for combined moment + compressive load with FOS $\geq$ 1.5

Failure-Avoidance Enhancements:
Added linear bearing rail system to eliminate bending moment transfer to chassis CF paneling, and steering stops to limit rack travel and ensure reliability under realistic racing loads.

## Impact

Delivered a structurally validated, competition-ready steering system with:

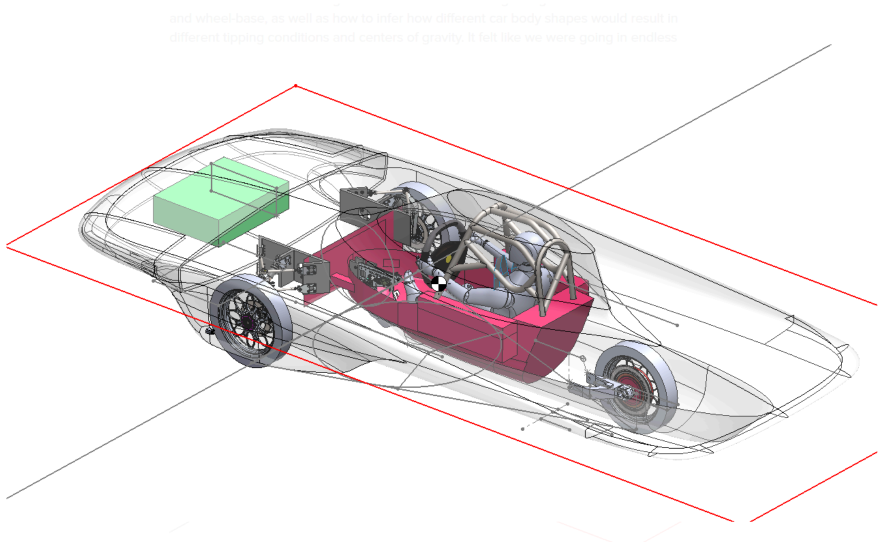
- Verified compliance with turning radius & geometry constraints from other subsystems
- Dramatically improved rigidity/simulations vs. the previous vehicle
- Reduced local rack mount panel stress and avoided historical failure modes from Gen-10
- Safer steering response under extreme driver load conditions
- Clear manufacturable drawings, BOM, and installation guidelines for team implementation and future generational knowledge transfer

## Skills Demonstrated

- Steering system architecture & Ackermann geometry design
- Load case development + worst-case engineering safety evaluation
- Extensive FEA validation (buckling, combined load, joint stress, bolt preload analysis)
- CAD master assembly development & linkage parametric derivation
- Integration of steering + suspension constraints, including anti-bump steering preservation
- Mechanical design for manufacturability, reliability, and serviceability

## 2. Stability Analysis Tool

**Detailed Critical Design Review Slidedeck** ***(first 8 slides)***



### Objective

Developed a vehicle-level stability analysis tool to guide early architectural decisions for CalSol's 11th-generation solar vehicle, including track width, wheelbase, ground clearance, and mass distribution. The tool was designed to quantitatively verify static tipping safety while enabling rapid iteration across multiple, interdependent subsystems during early-stage vehicle layout.

### Methodology

Defined stability functional ASC regulations and constraints

- No tipping when the vehicle is tilted 45° about an axis formed by any two wheels
- Minimum 104 mm ground clearance (regulation minimum: 100 mm)
- Compatibility with our trailer packaging constraints
- Steering geometry constraints: wheel angles < 25° while maintaining a 7.5 m turning radius

Integrated all major mass-dominant components

Using subteam-provided values (including worst-case mass uncertainties) and updated estimates:

- Roll cage, driver, pedal mount, seat belt system
- Steering wheel, battery, electrical system, solar array
- Rims & tires, motor, suspension components

Leveraged SolidWorks mass property calculations to dynamically compute center of gravity (CoG) as component placement, vehicle dimensions, and packaging evolved.

Evaluated tipping conditions using two criteria:

- Actual CoG height must be less than the distance from the CoG to the tipping axis formed by any two wheels
- Actual CoG height must be less than the maximum allowable geometric CoG

Geometric COG Constraint

Used a legacy trade-study calculator (developed by previous team members) to compute allowable CoG envelopes as a function of track width and wheelbase.

- For 1.55 m track width and 2.3 m wheelbase, maximum allowable CoG height: 21.92 in

Validated final subsystems configuration

- Actual CoG height: 18.88 in
- Distances to tipping axes: 19.79 in, 19.83 in, 28.51 in
- Result: tipping condition satisfied with 0.91 in vertical margin

Identified dominant contributors to CoG sensitivity, noting that roll cage and top shell had the largest negative influence on vertical stability margins, and the battery was our primary mode of shifting the COG forward

## Impact

This tool served as the backbone for early vehicle architecture decisions, preventing isolated subsystem design that could compromise global stability. By centralizing mass properties and stability validation, the team avoided circular redesign loops, reduced unnecessary iteration time, and confidently locked in vehicle dimensions before committing to detailed subsystem designs. The model enabled cross-team alignment, ensured compliance with static stability requirements before hardware fabrication began, and defined the locations of mass-dominant items.

## Skills Demonstrated

- Vehicle-level systems thinking and architectural trade studies
- Center-of-gravity modeling and static stability analysis
- CAD-driven mass property management and configuration control
- Cross-subsystem integration (chassis, suspension, steering, shell, electrical)
- Engineering decision support tooling and design bookkeeping for large teams

# 3. Bolt Preload Calculator

| Parameter | Value | Units |
|---|---|---|
| Bolt Material # from Material Table | 43 | |
| Yield Strength, Sty | 275.79 | MPa |
| Thread Size | #10-32 | - |
| Nominal Diameter, dnom | 4.83 | mm |
| Tensile Stress Area, At | 0.1290 | cm^2 |
| Preload % of Yield, %yld | 66.7 | % |
| Torque Coefficient, KT | 0.2 | - |
| Preload Uncertainty, %uncrt | 25 | % |
| Preload Relaxation, %relax | 10 | % |

Bolt Selection

Inch ☑ Metric ☐

Results

| Preload Force, FPL (N) | Install Torque, T (N·m) | % of Yield Strength | Torque Coefficient, KT |
|---|---|---|---|
| 2,373 | 2.2903 | 66.7 | 0.2 |

The nominal value is the design target, and the min and max values account for preload uncertainty and relaxation.

| | Nominal | Minimum | Maximum |
|---|---|---|---|
| Preload Force (N): | 2,373 | 1,542 | 2,966 |
| % of Yield Strength | 66.7 | 43.355 | 83.375 |

Preload (% of Yield)

| When to Use | Preload (% of Yield) | Notes |
|---|---|---|
| Conservative, moderate/variable loads | 50% | Shigley/Lindeburg recommendation |
| Balanced preload, general critical joints | 60% | Safer with slightly better clamping |
| Rule of thumb, general use | 66.70% | Common default, good balance |
| High preload, static-heavy joints | 75% | Only if ductility & design allow |
| Max preload (proof strength) | 85% | Beyond this risks plastic deformation |
| Avoid unless specialized application | >85% | Use only with testing or FEA |

Torque Coeffienct

| Bolt Condition | $K_T$ |
|---|---|
| Nonplated, black finish | 0.3 |
| Zinc-plated | 0.2 |
| Lubricated | 0.18 |
| With Anti-Seize | 0.12 |

Reference Shigley

Preload Uncertainty

| Tightening Method | Accuracy |
|---|---|
| By feel | ±35% |
| Torque wrench | ±25% |
| Turn-of-the-nut | ±15% |
| Load indicating washer | ±10% |
| Bolt elongation | ±3-5% |
| Strain gages | ±1% |
| Ultrasonic sensing | ±1% |

Reference Machinery's Handbook

Preload Relaxation

Preload loss allowance approximately 10% is sufficient as a general rule

Reference Machinery's Handbook

## Objective

Designed a bolt preload calculator and SolidWorks simulation tutorial to improve the accuracy and consistency of joint design across CalSol's mechanical systems. The goal was to eliminate undocumented torque assumptions, prevent unsafe over-preloading, and enable reliable bolted-joint simulation within SolidWorks FEA workflows.

## Methodology

Developed a spreadsheet-based engineering tool that bridges analytical joint design and simulation:

<u>Allowed users to input joint-specific parameters</u>

- Bolt material and grade (e.g., SAE J429 Grade 8, Class 10.9, etc.)
- Thread size and pitch (metric or imperial)
- Torque coefficient based on surface condition (zinc-plated, dry, lubricated)
- Assembly method accuracy (torque wrench, turn-of-nut, etc.)
- Implemented a preload-as-percent-of-yield framework with clear guidelines

<u>Easy to use output</u>

Minimum, nominal, and maximum installation torque values (N·m) accounting for preload uncertainty and relaxation.

Integrated directly into the team's SolidWorks Simulation workflow by using calculated torque values as bolt preloads for combined loading analysis.

[Documented Solidworks Tutorial]

Complemented the calculator with easy-to-follow guidelines linked above to teach members how to properly model bolted connections and evaluate bolt Factor of Safety (FOS) under realistic loading conditions.

## Impact

This tool standardized bolted-joint design across the team, replacing guess-based torque values with traceable, defensible engineering inputs. It reduced the risk of over-preloading, which can artificially lower bolt and part FOS in simulation while improving confidence in joint performance under real loading. The calculator also served as long-term documentation, enabling team members to design and simulate joints consistently across vehicle generations.

## Skills Demonstrated

- Mechanical joint design and fastener mechanics (Shigley and Machinery's Handbook referenced)
- Preload selection, torque uncertainty, and yield-based design practices
- Integration of analytical tools with FEA workflows
- Development of reusable engineering tools for large teams
- Technical documentation and knowledge transfer